The Effect of Auditory Localization on Task-evoked Pupillary Response

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Running head: AUDITORY LOCALIZATION AND PUPIL RESPONSE

Abstract

The purpose of this study was twofold: 1) to replicate an experiment in the research of Rhodes (1987) which found that reaction times (RT) necessary to localize a sound increased linearly up to 90 degree eccentricities from the focus of attention; and, 2) to test the hypothesis that if shifting auditory attention is a resource dependent, serial process, then a measure of capacity--the task-evoked pupillary response (TEPR)--should reflect the relationship between capacity and auditory attention shifts. More specifically, progressively larger TEPRs should be produced as the angle of auditory attention shift increases. Twenty undergraduates (10 of each gender) received course credit for participation. Pupil and RT data were obtained while subjects made attention shifts in 45 degree increments from 0--180 degrees. Results from the TEPR data did not support that hypothesis; however, a very unusual but highly significant interaction between pupil diameter and direction of speaker numbering (clockwise vs. counterclockwise) was found. Nonetheless, Rhodes' (1987) findings in terms of RT were replicated and seem to represent a quite robust phenomenon.

The Effect of Auditory Localization on Task-evoked Pupillary Response

The location of a sound in space is primarily determined by computing interaural time difference and interaural intensity difference cues. Therefore, as long as a sound is not located in a position which is known to be difficult to localize (e.g., on the median plane or the cone of confusion; Mills, 1972), one would expect the time necessary to localize a sound regardless of its position in space to be constant. However, in a recent study by Rhodes (1987), a linear relationship was found between reaction time (RT) and angle of auditory attention shift up to 90 degree eccentricities from the focus of attention. If accurate, this suggests that auditory localization entails the use of a topographically oriented representation of a sound's location in real space at higher levels of processing (i.e., after interaural time and intensity differences have been computed at lower levels).

Although this type of topographical map has been found in the brains of animals (e.g., owls; Knudsen, 1982, 1984 and cats; Middlebrooks & Pettigrew, 1981), humans have not been tested (single-cell recordings are used in animal studies which cannot be used with humans). Because Rhodes' (1987) work was the first to operationally define and test a possible behavioral measure of this phenomenon in humans, one goal of this study is to replicate one of the experiments in Rhodes' (1987) work.

Additionally, Rhodes (1987) has proposed that auditory localization is a resource dependent, serial process. This contention can be tested behaviorally with the task-evoked pupillary response (TEPR) which has been shown to be a measure of capacity. Kahneman and Beatty (1966), for example, studied the TEPR in conjunction with a digit span task and found that pupil dilation increased as the number of digits heard increased, peaked immediately before recall, and decreased as each digit was recalled (i.e., memory space was freed up). Kahneman and Beatty (1967) used a pitch discrimination task in a similar vein and as expected found that the closer a comparison tone was to a standard tone (in terms of pitch), the larger the pupil dilation and higher the error rate. Further evidence in support of the claim that the TEPR is a measure of capacity was obtained within a dual task paradigm by Kahneman, Beatty, and Pollack (1967). In the most difficult condition, subjects performed a digit transformation task (adding digits) and a visual detection task in which detection of a target letter among groups of five letters presented at 1 s intervals was required. Pupil dilations while performing both tasks simultaneously were larger (as were error rates) than when either task was performed alone. The second purpose of the present study, then, is to test the hypothesis that if auditory localization is a capacity based, serial process, then TEPRs should be progressively larger as the angle of auditory attention shift increases.

Method

Subjects

Twenty Ball State undergraduates (10 of each gender) received course credit for participation. There were 18 right-handed and 2 left-handed subjects with an average age of 19.75 years. Using the Snellen visual acuity method, the average visual acuity for the left and right eyes were 20/23.75 and 20/25.65, respectively. Five subjects were eliminated and replaced because of pupil imaging difficulties.

Stimuli and Apparatus

An Apple IIe-Cyborg ISAAC 91A workstation was used in conjunction with Coulbourn Instruments timer, tone generator, and audio gate to present a 1-KHz sine wave tone for 100 ms at 60 dB (SPL) via 2" Radio Shack speakers. Five such speakers were centered at the top of the headrest in a semicircle, radius 42 cm, in front of the subject with 45 degree intervals between speakers (starting and ending at the subject's ears). The speakers were assigned numbers 1 through 5 in clockwise and counterclockwise order which was counterbalanced across subjects.

Subjects were asked to fixate a red dot centered on a 53 cm^2 white screen from 1.41 m for the 10 s trial duration. Pupil diameter was measured by an Applied Sciences Lab, Model 1000, Infrared T.V. Pupillometer under 19.9 cd/m^2 luminance. Data from the pupillometer were acquired by the Apple IIe workstation at 4 samples/s starting 5 s prior to and ending 5 s after stimulus presentation. A Narco Biosystems, Narco Trace 80, chart recorder was used to record analog pupil diameter for purposes of editing artifacts from the pupil data.

Subjects verbally responded with the number of a speaker which triggered a voice activated switch which in turn stopped a Gerbrands digital millisecond clock/counter (reaction timer). RT and localization accuracy were recorded by hand.

Procedure

It was explained to the subjects that their goal was to verbally indicate by a number from which of five speakers a tone had come as quickly and accurately as possible without making any unnecessary sounds, verbalizations, or body movements. The speaker numbering system was explained, and the subjects were further informed that the speaker from which the tone had been previously presented would be repeated more than what one would expect at random. Therefore, they would be quicker and more accurate if they returned their attention to the previous speaker location prior to each trial. Subjects were not only told that it would improve their performance if they did this, but they were also informed of the importance of returning their attention to the previously sounded speaker in terms of success of the experiment. Due to intertrial intervals of considerable length (e.g., up to 45 s), each subject was reminded prior to each trial to which speaker they should return their attention. Special emphasis was also placed on the fact that the subject would need to keep their eyes open and remain still during the 10 s trial duration (a headrest helped in this regard).

After reminding the subject to which speaker to attend, the experimenter ascertained whether the subject was ready to begin by asking, "Ready?" If no response was given and the subject's eyes were fixated, the experimenter said, "Begin." After 5 s, the tone was presented and the subject responded and remained still with eyes fixated for an additional 5 s until the experimenter said, "Relax."

Since pilot studies indicated localization errors occurred very infrequently, subjects were told that if a localization error was made, they should not worry about it but simply tell the experimenter the correct number at the end of the trial. It was occasionally necessary to deviate from the experimental trials and run a few sham trials to avoid response expectancies if a series of errors were made by either the subject, experimenter, apparatus, or any combination of the above. The subject was given accuracy feedback during sham as well as experimental trials. This continued until 40 experimental trials were complete.

Results

Errors

There were four types of errors which could have caused a trial to be re-run. RT errors were scored when a subject's RT was faster than 250 ms or slower than 3000 ms. Localization errors were recorded if the subject failed to make the correct localization and did not correct their error at the end of the trial. The third type of error occurred if pupil diameter was not acceptable (i.e., subject was responsible for artifacts such as blinks). The fourth type of error involved experimenter mistakes which included setting erroneous limits in terms of pupil data, inadvertently beginning a trial before either the subject or the experimenter were ready, etc. All errors combined produced an error rate of less than 11.5% with localization errors occurring 1.25% of the time.

Reaction Time

Each subject's median RT for a given angular shift of attention (i.e., 0, 45, 90, 135, 180 degrees) was averaged across subjects. See Table 1 for averaged median RTs.

Insert Table 1 about here

A repeated measures ANOVA with Greenhouse-Geisser correction yielded a highly significant main effect for angle of attention shift $F(4,72) = 4.43$, $p < .0084$. The highest level significant trend was quadradic $F(1,18) = 8.65$, $p < .0087$. As can be seen from Figure 1, RT increased as a function of angular distance from the focus of attention up to approximately 135 degrees at which point RT decreased dramatically which parallels Rhodes' (1987) findings (see Figure 2).

Insert Figures 1 and 2 about here

Development of Averaged Pupil Data

Raw pupil data were used in computing 5 s baseline means for each trial. The baseline mean for a trial was then subtracted from each time sample for that trial. Next, the four deviation time samples per second per trial were averaged which resulted in 10 averaged deviation time samples per trial.

Averaging across trials was done by averaging corresponding averaged deviation time samples across the five different types of trials (which had the following number of elements per subject: 12, 7, 7, 7, and 7 at 0, 45, 90, 135, and 180 degree eccentricities, respectively).

Pupil Data

A repeated measures ANOVA with Greenhouse-Geisser correction was performed and revealed a highly significant time samples by direction of speaker numbering interaction $F(5,90) = 6.41$, $p < .0052$. The highest level significant trend was quadradic $F(1,18) = 7.08$, $p < .0159$. Referring to Figure 3, one can easily see that pupil dilation of subjects in the clockwise speaker numbering condition peaked shortly after subject response and then continually constricted until the end of the trial. However, the dilations of subjects in the counterclockwise speaker numbering condition peaked shortly after subject response but then remained significantly larger than those of subjects in the clockwise numbering condition. It is important to note that the maximum TEPR was nearly the same for each eccentricity (i.e., not progressively larger as hypothesized).

Insert Figure 3 about here

Discussion

The present study replicated Rhodes' (1987) findings that there is a linear relationship between RT and degree of auditory attention shift up to about 90 degrees from the focus of attention. However, no attempt at an exact replication was made. This study was modeled after Rhodes' (1987) experiment 1 in which the stimuli were 100 ms, 1500 Hz sine wave tones (cf. 100 ms, 1000 Hz sine wave tones), over 9 speakers equally spread throughout a semicircle (cf. 5 speakers similarly arrayed) at a radius of 50 cm (cf. radius of 42 cm). Both studies used a similar repeat rate 29% (cf. 30%). Subjects in Rhodes' (1987) study initiated each trial immediately after the previous trial and were given no accuracy feedback during experimental trials. In this study, subjects were reminded to which speaker to attend prior to trial initiation by the experimenter and were given accuracy feedback after each experimental trial and they were, of course, not blindfolded. Subjects were also allowed to correct localization errors here whereas they were not in Rhodes' (1987) study. In addition, this experiment was conducted in a normal open space lab instead of a sound-attenuated chamber.

Since a mere 1.25% localization error rate existed, errors were not analyzed further. This low error rate may be attributed to at least two factors. Subjects in the current study could correct their errors and they had fewer speakers from which to chose (5 cf. 9). It has also been shown (Warren, 1970; Jones & Kabanoff, 1975) that localization is more accurate when subjects are allowed to keep their eyes open. These factors may also account for the fact that RTs in the present study are faster and leveled off between 90 and 135 degrees (cf. slower overall RTs and RTs which continued to slow until about 135 degrees in Rhodes' (1987) work).

The hypothesized relationship between TEPR and attention shift was not supported. Nonetheless, possible explanations for the time samples by direction of speaker numbering interaction are worth further investigation. For example, the TEPR in the counterclockwise condition of this study is not a totally unheard of response. Johnson (1971) found that if subjects needed to rehearse several digits to be recalled later, their pupils remained dilated until allowed to stop rehearsing. Perhaps by letting subjects correct their errors a confound was introduced. Since subjects in the counterclockwise speaker numbering condition were responding directly counter to the natural serial position of the number sequence 1--5 in an English speaking society, maybe they were less certain of their responses and continued to think about their response throughout the remainder of the trial (causing continued pupil dilation). Another interesting study could be conducted using subjects who read only from right to left to see if the opposite effect is found (i.e., an interaction where subjects in the clockwise speaker numbering condition would have sustained pupil dilations).

In conclusion, a linear relationship between RT and degree of attention shift from the focus of attention as demonstrated in Rhodes' (1987) work was replicated and seems to be a robust phenomenon in that strict adherence to Rhodes' (1987) method and stimuli parameters were not exercised. However, the claim that auditory localization is a capacity based, serial process was obviously not supported by the TEPR data. Because the previously mentioned confound may have occurred, further study on the hypothesized relationship between TEPR and shifts in auditory attention may be warranted (e.g., a study using names instead of numbers to identify speakers would rule out any habitual response which may exist with numbers). There is, however, good reason to believe a confound was not responsible for the TEPR findings. For example, one would suspect that the hypothesized confound could effect the TEPR only after the localization (i.e., subjects could not have tried to verify their responses until after they made them). TEPR data support this view in that peak dilations (which occurred shortly after localization) were nearly identical regardless of angle of attention shift and TEPRs did not differ until later in the trial. Therefore, instead of attributing the TEPR findings to a confound, a more plausible conclusion is that auditory localizations are not capacity based, serial processes.

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Table 1

Average Median Reaction Times (in milliseconds) for Corresponding Attention Shifts (in degrees) from the Focus of Attention

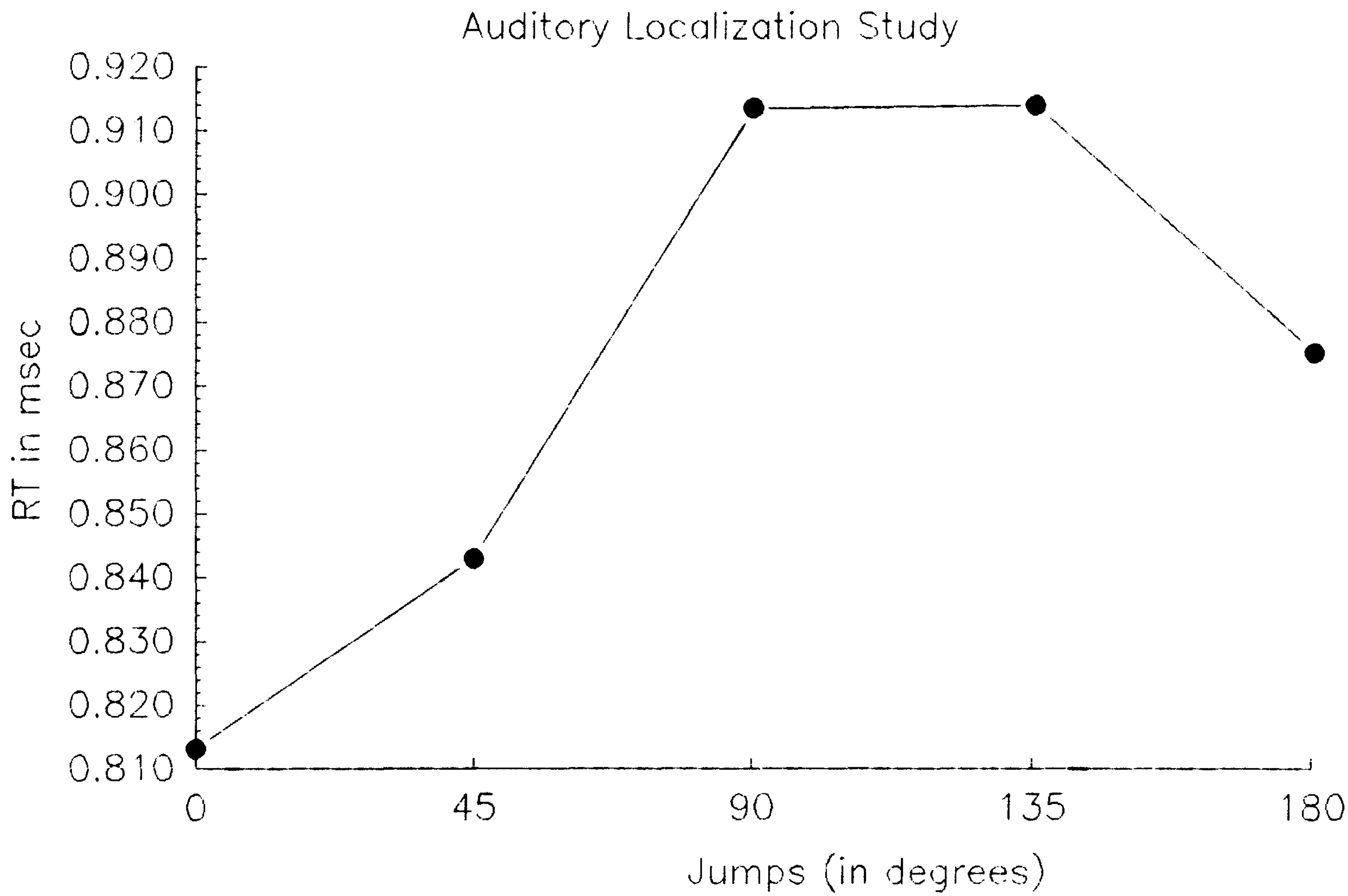
Jump Eccentricity (degrees)	Average Median Reaction Time (ms)
0	.8132
45	.8431
90	.9134
135	.9139
180	.8752

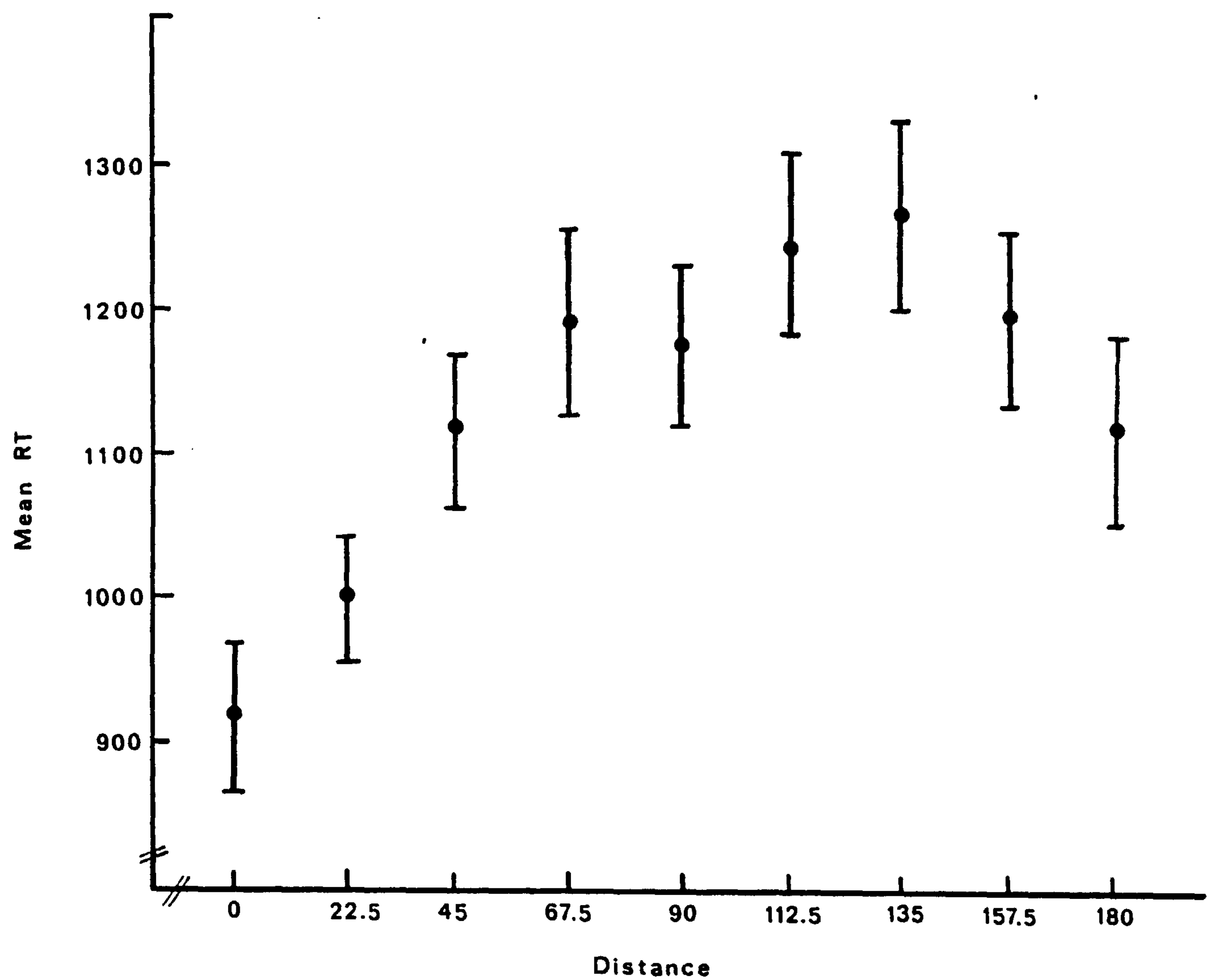
Figure Captions

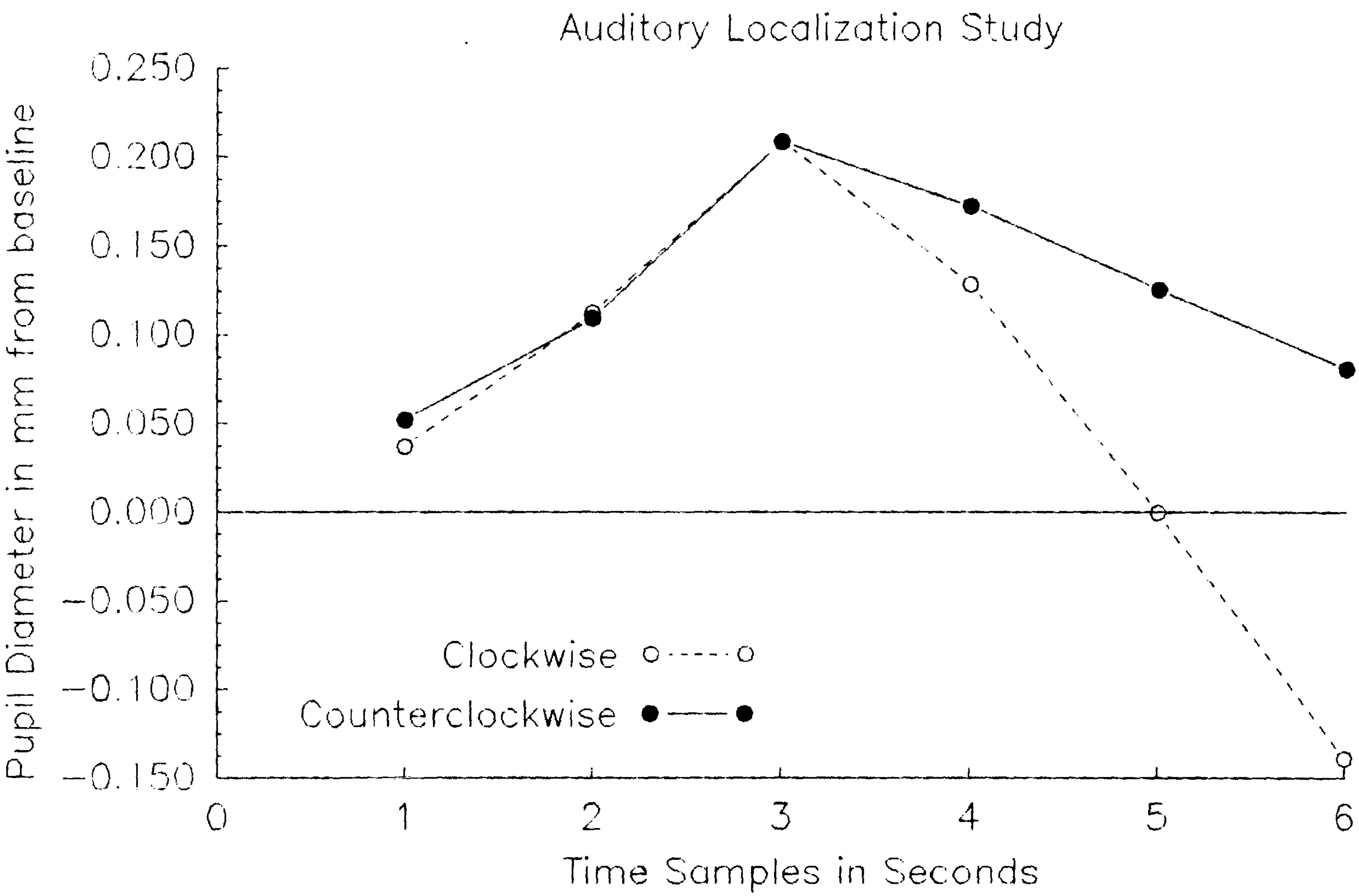
Figure 1. Averaged median reaction times (in milliseconds) as a function of jump eccentricity (in degrees) from the focus of attention.

Figure 2. Average reaction time (in milliseconds) as a function of jump eccentricity (in degrees) from the focus of attention (from Rhodes, 1987).

Figure 3. Pupil diameter (in millimeters from baseline) as a function of clockwise vs. counterclockwise speaker numbering conditions.


Auditory Localization Study
0.920
0.910
0.900
0.890
0.880
0.870
0.860
0.850
0.840
0.830
0.820
0.810
RT in msec
0
45
90
135
180
Jumps (in degrees)


Mean RT
1300
1200
1100
1000
900
0
22.5
45
67.5
90
112.5
135
157.5
180
Distance



Auditory Localization Study
Pupil Diameter in mm from baseline
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
0
1
2
3
4
5
6
Time Samples in Seconds
Clockwise
Counterclockwise